The Slow Neutron Resonant Scattering of Gold*

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ALTHOUGH much information has been accumulated concerning slow neutron resonances, relatively little experimental evidence is available concerning the detailed energy dependence of the scattering cross section near a resonance.

Using the apparatus described previously,[1] in conjunction with the Columbia slow neutron velocity spectrometer,[2] the 4.87-ev Au resonance[3] has been investigated with results in excellent agreement with theory, and the level parameters have been evaluated.

TABLE I. Level widths and neutron cross sections in gold.

	Γ_{NO}	Γ	σ_{P2}	σ_{P1}
$J_1=1$	(0.0211 ± 0.002)	(0.172 ± 0.010)	(10.6 ± 0.6)	(13.3 ± 1.3)
$J_1=2$	(0.0163 ± 0.0015)	(0.133 ± 0.010)	(17.6 ± 0.9)	(8.0 ± 1.4)

If a sample is thick enough to give very small transmission and if the ratio of the scattering to total cross sections, (σ_s/σ_t), is less than about 0.5, in which case the diffusion length is less than the sample thickness, then the ratio of the sample counting rate to that of a reference thick graphite sample, (N_x/N_C), is independent of sample thickness and depends only on the ratio (σ_s/σ_t). A calibration curve for (N_x/N_C) *vs.* (σ_s/σ_t) was obtained, for our geometry, using thick B_2O_3 and Ni_2B standards. The scattering and $1/v$ terms for the standards were determined by transmission measurements to give $(\sigma_s/\sigma_t)B_2O_3=(1+10.4E^{-\frac{1}{2}})^{-1}$ and $(\sigma_s/\sigma_t)Ni_2B=(1+3.31E^{-\frac{1}{2}})^{-1}$.

Using this calibration, the ratio (σ_s/σ_t) was measured for a thick gold sample in the vicinity of the resonance, and compared with theoretical curves based on the Breit-Wigner one-level formulas of the form[4]

$$[\sigma_c=\sigma_{co}\Gamma^2(E_0/E)^{\frac{1}{2}}]/[4(E-E_0)^2+\Gamma^2] \quad (1)$$

$$\sigma_s=(G_2\sigma_{P2})+4\pi G_1\{R_1^2+[\lambda\!\!\!^{-}{}_0^2\Gamma_{NO}^2+4\lambda\!\!\!^{-}{}_0\Gamma_{NO}R_1(E-E_0)]/[4(E-E_0)^2+\Gamma^2]\} \quad (2)$$

$$\sigma_{co}=4\pi\lambda\!\!\!^{-}{}_0^2G_1\Gamma_{NO}\Gamma_Y/\Gamma^2. \quad (3)$$

Gold has one stable isotope of spin $\frac{3}{2}$, so $J_1=1$ or 2 and $G_1=\frac{3}{8}$ or $\frac{5}{8}$ for the "resonant spin state," and $G_2=\frac{5}{8}$ or $\frac{3}{8}$ for the "non-resonant spin state." The first term on the right in Eq. (2) is the constant (potential) scattering of the "non-resonant spin state." The second term gives the potential, resonance, and interference terms in the scattering for the "resonant spin state." The symbols have their usual significance.

The value $\sigma_{co}\Gamma^2=(638\pm17)$ barn-ev^2 in Eq. (1) was determined by a least squares fit to σ_t (from transmission measurements) in the thermal energy region. With $\sigma_{co}\Gamma^2$ fixed, only Γ_{NO}/Γ, $(G_2\sigma_{P2})$, R_1, and J_1 remain as undetermined parameters. Near 2 to 3 ev the scattering is nearly zero for the resonant spin state, so (σ_s/σ_t) determines $(G_2\sigma_{P2})=(6.6\pm0.33)$ barns. For a given choice of $\sigma_{co}\Gamma^2$ and the *total potential* scattering, almost identical curves for (σ_s/σ_t) result for $J_1=1$ and $J_1=2$, when suitable related choices are made for (Γ_{NO}/Γ) in the two cases, so further evidence is needed to determine J_1. When J_1, $\sigma_{co}\Gamma^2$, and $G_2\sigma_{P2}$ are given, (σ_s/σ_t) is mainly sensitive to (Γ_{NO}/Γ) near resonance, and to R_1 far from resonance on either side. Thus, both of these parameters can be evaluated by comparison with experiment to give Table I.

The values of σ_{P2} and other results[5] indicate strongly that $J_1=1$. A detailed report of this work will be published shortly.

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Screening of Electronic Interactions in a Metal

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IN recent publications,[1,2] Landsberg and Wohlfarth have shown that the assumption of a screened Coulomb interaction between electrons in a metal eliminates certain difficulties arising from the treatment of the effects of the exchange energy according to the free particle approximation. With the free particle approximation, the exchange contribution to the Coulomb interaction energy of two electrons of wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$ is $W_{1,2}=-2\pi e^2/L^3|\mathbf{k}_1-\mathbf{k}_2|^2$, where $\mathbf{k}=\mathbf{p}/\hbar$ and $\mathbf{p}$ is the electronic momentum. For a given electron, the total energy of interaction with all the other electrons is

$$W_i=\sum_{j\neq i}W_{i,j}=-\frac{e^2k_0}{2\pi}\left(2+\frac{k_0^2-k^2}{k_0k}\ln\left|\frac{k+k_0}{k-k_0}\right|\right),$$

where k_0 is the absolute value of the wave vector of an electron at the top of the Fermi distribution, and all of the levels are assumed to be occupied up to k_0. Since the E *versus* k curve for a given electron becomes very steep as k approaches k_0, at low temperatures the density-in-energy of electron levels is correspondingly reduced. Bardeen[3] has shown that for this reason the specific heat of the electron gas should vary as $-\ln T/T$, in contrast to the linear dependence on T obtained when the exchange energy is ignored. Experiments indicate that a linear dependence is correct and therefore that calculations based on perturbation theory overestimate the effects of exchange energy. This overestimate is found also to lead to incorrect predictions at low temperatures for conductivity and diamagnetism, and for the soft x-ray spectrum. In fact, Landsberg proposed the screened Coulomb interaction on a purely empirical basis in order to obtain agreement with experiment for the width of the tail of the soft x-ray emission spectrum of sodium.

Simple mathematical analysis makes clear the fact that the increased steepness of the E *versus* k curve originates in the long range of the Coulomb interaction, which, as we have seen, leads to a very large exchange energy for electrons of nearly equal momenta. If, with Landsberg, one assumes the Coulomb force to be screened, then one will no longer obtain so large a modification of the E *versus* k curve. Wohlfarth showed that a linear dependence of the specific heat on temperature is regained, and that agreement with experiment is obtained with a potential $V=(e^2/r_{ij})\times\exp(-r_{ij}/\lambda)$ when the screening radius λ is chosen to be of the order of 10^{-8} cm, the value introduced by Landsberg.

We have been led independently to the concept of an effective screened Coulomb force as a result of a systematic classical and quantum-mechanical investigation of the interaction of charges in an electron gas of high density. We have treated this problem with the aid of certain canonical transformations, which make possible a solution which is much more accurate than the perturbation theory solutions on which previous calculations have been based.[4] Our results show that the Hamiltonian for a system containing a high density of electrons can be split into two parts in a natural way. The first part corresponds to organized oscillations of the medium as a whole. These are the so-called plasma oscillations, which resemble sound waves and represent the long-range correlations brought about by the Coulomb force. At low temperatures, these oscillations are so weakly excited that they make a negligible contribution to the specific heat. The remainder of the Hamiltonian then reduces to a screened Coulomb interaction, since the long-range part of the interaction has been effectively included in the oscillations of the medium as a whole. The screening radius is found to be $\lambda \cong v_0/\omega_p = (\hbar k_0/m)(m/4\pi n_0 e^2)^{1/2}$ where v_0 is the velocity of an electron at the top of the Fermi distribution, $\omega_p = (4\pi n_0 e^2/m)^{1/2}$ is the "plasma frequency," and n_0 is the electron density. For sodium, $k_0 \cong 0.9\times 10^8$ cm, and $\lambda \cong 10^{-8}$ cm, in agreement with the screening radius adopted empirically by Landsberg and Wohlfarth.

A more detailed report of this work is being prepared for publication.

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Neutron Yield from $Be^9(\gamma,n)Be^8$ Reaction*

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Although the $Be^9(\gamma,n)Be^8$ reaction is one of the most commonly employed neutron sources, only a small amount of information is available concerning the obtainable neutron flux under various conditions. In the experiments reported here, the thickness of the beryllium target necessary to yield the maximum slow neutron flux was determined.

With a 200-gram powdered beryllium target and a Van de Graaff generator as an x-ray source, Wiedenbeck[1] compared the neutron yield directly with that of a Ra-Be source. He obtained a yield equivalent to 10^3 curies of radium with an electron accelerator potential of 3.2 Mev and a beam current of 100 μamp.

The present measurements have also been made with a Van de Graaff accelerator, but at a potential of 2.5 Mev and a 100 μamp. electron current. The beryllium target consisted of solid square pieces of beryllium (9×9 cm) of various thicknesses. These were placed about 3 mm from the x-ray exit window. Directly beneath the last beryllium block a stack of large thin paraffin plates (35 cm in diameter) were mounted. Copper and indium foils were placed (with and without cadmium covers) at different depths between the paraffin plates, and on the axis of the x-ray beam. Their induced activity was taken as a measure of the slow neutron flux. The highest activity was observed with about 2 cm of paraffin between the beryllium target and the detector foil. When the beryllium target was also surrounded by paraffin, the slow neutron flux at points below the target increased only slightly.

Under the above conditions and with a 4 cm thick beryllium target, the slow neutron flux was observed to reach a maximum density of about 10^7 neutrons/cm²/sec., while at thicknesses of 2 and 7 cm, the flux is only 85 percent of the maximum value. The neutron production increases in proportion to the amount of beryllium penetrated by the x-rays. Therefore, the activity of the foils decreased as the thickness of the beryllium target was reduced below 4 cm. However, with a beryllium target more than 4 cm thick, the activity of the foils also decreased because of the effect of the inverse square law. With increasing target thickness fewer neutrons reach the detector foils beneath it, regardless of the fact that the total neutron production increases. A reduction of the target dimensions from 9×9 to 5×5 cm reduces the flux by a factor of three. As a result of the predominantly forward direction of the x-ray beam, an increase in target diameter beyond 9 cm had little effect on the neutron flux.

Measurements with a BF_3 counter placed five feet from the beryllium target in a plane perpendicular to the x-ray beam showed an increase of the neutron flux with target thickness up to 15 cm. At greater thicknesses, a steady value of the neutron flux was obtained. Although neutrons from any point of the target have about equal probability of reaching the counter, the attenuation and divergence of the x-ray beam limits the increase of the total neutron emission with increasing amount of target material.

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Half-Life of Cu^{66}

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In 1949 Silver[1] reported precision measurements of the decay periods of a number of isotopes using a differential ionization chamber with a vibrating reed condenser electrometer and feedback amplifier. The half-life of Cu^{66} was found to be 4.34 ± 0.03 minutes. We were unable to reconcile this value with an activity obtained in copper which had been exposed to photo-neutrons, and we have therefore made a careful measurement of this half-life.

Lead bricks were piled in front of the "22"-Mev betatron to absorb the gamma-ray beam and to provide a source of photo-neutrons. An electrolytically pure copper disk was placed at the center of a block of paraffin beside the lead bricks. After the lead had been irradiated for 11 minutes, the copper disk was counted with an end-window β-counter connected through scalers to a time-stamping machine. The decay curve shown in Fig. 1 is that

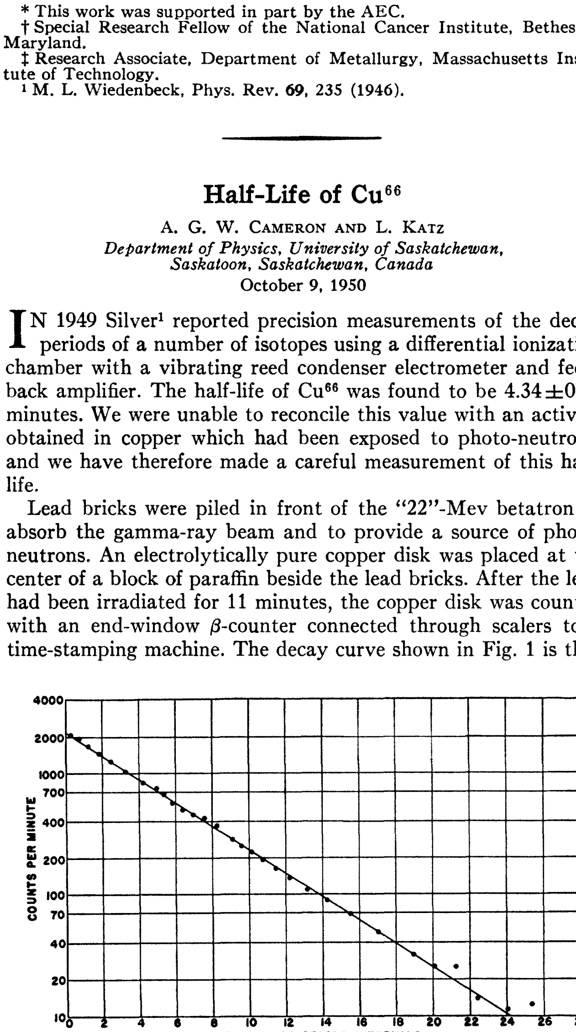

Fig. 1. Decay of Cu^{66}. The background of 34 counts/min. and a long-lived activity of 7 counts/min. have been subtracted.

obtained after subtraction of background of 34 counts/min. and a long-lived activity of 7 counts/min. (presumably 12.9 hour Cu^{64}).

A similar irradiation was made with a copper disk surrounded by cadmium. The initial activity of this disk was only 50 percent above background. This established that the activity of Fig. 1 resulted from the capture of slow neutrons by copper, and hence must arise from the reaction $Cu^{65}(n,\gamma)Cu^{66}$.

We therefore find the half-life of Cu^{66} to be 5.18 ± 0.10 minutes. This is in good agreement with the old value of 5 minutes measured by Amaldi *et al.*[2]

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